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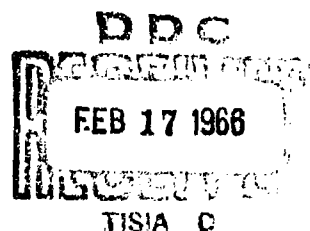
**Communications Reliability of Transmissions  
from Naval Radio Station (T),  
Jim Creek, Washington, NPG at 24.0 KC/S**  
[Unclassified Title]

W. E. GARNER

*Communication Branch  
Radio Division*

January 7, 1966

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#### ABSTRACT

In 1968, the operating frequency of the very-low-frequency (vlf) transmitting station NPG, located near Seattle, Washington, was changed from 18.6 kc/s to 24.0 kc/s. DECO Electronics, Inc., was contracted to predict the communication reliability of the NPG 24.0 kc/s transmissions in the western Pacific Ocean area. Through the generosity of a Japanese research group at the Inubo Radio Wave Observatory in Choshi, Japan, some experimental data were obtained and have been used to evaluate the DECO predictions in a portion of the area covered, the southeast coast of Japan.

Comparison of the experimental and predicted data show very good agreement. The received field strengths, as observed, were slightly higher than predicted. The predicted atmospheric noise levels showed very close agreement with the measured data. The observed communication reliability was about 76 percent for manual cw, and was predicted to be about 52 percent. For automatic teletype, the observed and predicted reliabilities were 84 and 62 percent, respectively. Therefore, for the ocean area in the vicinity of southeast Japan, the reliability of NPG 24.0 kc/s transmissions, assuming a radiated power of 250 kw, would be better than predicted.

#### PROBLEM STATUS

This is an interim report on one phase of this problem; work is continuing on this and other phases.

#### AUTHORIZATION

NRL Problem 54R01-39  
BUSHIPS Problem SR008-01-01 Task 7028

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COMMUNICATIONS RELIABILITY  
OF TRANSMISSIONS FROM  
NAVAL RADIO STATION (T),  
JIM CREEK, WASHINGTON,  
NPG AT 24.0 KC/S

INTRODUCTION

Efficient deployment of fleet ships requires an ability to predict the reliability of communications over a long period of time and in any ocean area of the world. One of the missions of the ELF-VLF Propagation Center established at the U.S. Naval Research Laboratory (NRL) is to provide the Navy with very-low-frequency (vlf) communication-reliability prediction information for all the ocean areas and to update this information continuously.

In carrying out the mission of the ELF-VLF Propagation Center, NRL contracted to have DECO Electronics, Inc., predict the communication reliability, in the western Pacific Ocean area, for the vlf transmissions from the Naval Radio Station (T), Jim Creek (NPG) at an operating frequency of 24.0 kc/s. At the time of this contract there were comparatively little experimental data available for this frequency for determining the various propagation parameters.

From October 1963 through May 1964, NPG transmissions were made at a frequency of 24.0 kc/s. Through the generous cooperation of Mr. Akira Sakurazawa, the former Director, and Mr. Katsuhiro Yamada, the present Director of the Inubo Radio Wave Observatory in Choshi, Japan, NRL has received data on the field strengths of these 24.0 kc/s transmissions and atmospheric noise recorded at Choshi. These data provide the only reliable, experimental information available for evaluating the accuracy of the DECO (1) predictions and for updating them. Recently, however, there have been two experiments, one airborne and one ground based, performed in the western Pacific Ocean area to obtain a better understanding of vlf propagation in these areas at frequencies above 20 kc/s. The airborne experiment was performed and reported by NRL (2), while the ground-based work was carried out by DECO Electronics, Inc., and will be reported soon.

The purpose of the present report is to publish the experimental data recorded at Choshi, Japan, by the Japanese investigators and to compare these data with the predictions

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by DECO for that area. The transmission field-strength data can be extrapolated to other areas of the western Pacific Ocean, but the great variability of the atmospheric noise in that area precludes any extrapolation of the signal-to-noise-ratio data.

CHOSHI DATA BACKGROUND

A vlf radio-wave-propagation research program has been carried out at the Inubo Radio Wave Observatory since 1960, or before. Until March 1964, Mr. Akira Sakurazawa was Director of this Observatory, and it was through Mr. Sakurazawa that NRL received the experimental data reported here. Mr. Katsuhiro Yamada is now the Director of the Observatory, and the informal exchange of unclassified vlf propagation information between that organization and NRL has continued.

The reporting of the Choshi data presented here has been delayed considerably while efforts were made to determine the techniques employed in recording the data and reporting it to NRL so that its processing and analysis by NRL would be more accurate. The differences in language and national customs prevented a complete understanding of these techniques. Therefore, certain assumptions, which are considered to have a high probability of being correct, had to be made by NRL. It has been assumed that the atmospheric-noise data recorded at the Inubo Observatory are the average values of the noise, and that the field-strength-measuring equipment was calibrated using an rms meter as the reference. It could not be ascertained whether the data as given to NRL were signal plus noise and noise, or signal and noise. It was assumed that the data were signal plus noise and noise. This assumption, therefore, if incorrect, produces pessimistic results. That is, it results in the field strengths of the NPG transmissions, as reported here, being equal to or slightly less than the true value. This means that the experimentally determined signal-to-noise ratios presented are also equal to or slightly less than the true values. The atmospheric-noise data were unaffected by this latter assumption.

The atmospheric-noise data recorded at Choshi were in an 80-cps bandwidth, but, except as noted, the data as reported have been normalized to a 100-cps bandwidth. The three-minute key-down and key-up periods provided by NPG approximately every hour or two hours were used for obtaining signal and atmospheric-noise data. The signals were received on a sloping wire antenna 40 meters long with the open end 20 meters above the ground. The receiving system was calibrated by use of

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a loop antenna and a standard field-strength meter.

It is impossible to state an absolute measurement accuracy, but it is believed that the overall accuracy should be consistent with the general state of the art for such long-term field-strength measurements.

#### CHOSHI EXPERIMENTAL DATA

The field strengths of the NPG (24.0 kc/s) transmissions and of the average atmospheric noise, and the ratio of these values (S/N) recorded at Choshi, Japan, from October 1963 through May 1964 are presented in various forms in Figs. 1 through 48.\* In these graphs, the NPG field strengths have been normalized to a radiated power of one kilowatt (kw), while the average atmospheric noise levels have been normalized to a 100-cps bandwidth, with the signal-to-noise ratios being the ratios of these normalized values. Figures 1 through 40 present the data on a monthly basis, with each successive group of five figures being the data for each succeeding month presented in the same formats. For instance, Figs. 1 through 5 are for October 1963. Figure 1 shows the hourly mean, plus and minus one standard deviation ( $\sigma$ ), of the NPG field strengths. Figure 2 gives the same type of information for the normalized signal to average atmospheric noise ratios (S/N), and the number above each data point indicates the number of data samples at that hour for the particular month. The same type of information as given in Figs. 1 and 2 is given in Fig. 3 for the average atmospheric noise. The number of data samples is identical for both signal and atmospheric noise field strengths and is the same as that given in the signal-to-noise ratio plots. The cumulative probability distribution of the NPG and average atmospheric noise field strengths, and normalized signal to average atmospheric noise ratios (S/N), are given in Figs. 4 and 5, respectively.

The data contained in Figs. 1 through 40 have been combined into seasonal cumulative probability distributions of the NPG transmissions, signal-to-noise ratios, and average atmospheric noise, and are presented in Figs. 41, 42, and 43, respectively. The cumulative probability distributions of the NPG field strengths and signal-to-noise ratios recorded when the propagation path was all in daylight, darkness, or transition are given in Figs. 44 and 45, respectively. The

\* All figures are bound consecutively at the end of this report.

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cumulative probability distributions of all data samples recorded between October 1963 and May 1964 for the NPG field strengths, signal-to-noise ratios, and average atmospheric noise are given in Figs. 46, 47, and 48, respectively.

It should be noted that the number of data samples recorded during the winter (December 1963 through February 1964, Figs. 41 through 43) is greater than for any other season, and, therefore, the winter data greatly influence the cumulative probability distributions plotted in Figs. 46 through 48. The period of the data and the number of data samples presented were limited by the duration of NPG transmissions at 24.0 kc/s and by the number of three-minute, key-down and key-up periods provided by NPG. There are only two months of data recorded during the fall season. Although three months of data were recorded for the spring season, the special NPG transmissions were sent only at two-hour intervals. Since the NPG transmissions were at 18.6 kc/s before October 1963 and after May 1964, there are no 24.0 kc/s data for the summer months. The seasons quoted, of course, are for the propagation path from NPG to Choshi, Japan, which is entirely in the northern hemisphere.

DECO PREDICTION METHODS

As previously stated, DECO Electronics, Inc., through a contract with NRL, predicted the field-strength probability and communication reliability for the NPG, 24.0 kc/s transmissions in the western Pacific Ocean area (1). These probability predictions were for all hours of the year and evolved from the following procedures.

1. The median field strengths of the transmissions were calculated using the waveguide-mode equation for many receiving points in the area of interest when the entire propagation path to each point was in daylight, transition, or darkness.

2. Since the field strength at a distant receiving point is not constant even for the same solar conditions, the distribution of the field strength with time had to be determined. Based partially on experimental data and partially on estimates of uncertainty factors, the standard deviation for this log-normal distribution was established.

3. The rms atmospheric noise levels, and their distribution with time for the various receiving points, were determined from Report 322 of the International Radio Consultative

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Committee (C.C.I.R.) (3).

4. The calculation of field-strength probabilities was done using the information in (1) and (2) above.

5. The communication-reliability predictions were calculated by time correlating the field-strength and distribution data from (1) and (2) with the atmospheric-noise data from (3).

In the calculation of the median field strengths, discussed in (1) above, the only time-dependent variable was the ionospheric condition; that is, whether the entire propagation path was in daylight, transition, or darkness. Consequently, the calculated field strengths had no seasonal dependence. This condition is normal for most field-strength predictions of this type. Therefore, the calculation of field-strength probabilities by DECO for all hours of the year was dependent upon the seasons only in that the number of hours that the propagation paths were in daylight, transition, or darkness varied with the season. The atmospheric-noise levels predicted by C.C.I.R. (3) have a diurnal and a seasonal dependence. Therefore, the communication-reliability predictions had both a seasonal and a diurnal dependence.

The above discussion of the methods used by DECO in arriving at their predictions provides background information for the comparison of the experimental data presented here with the predictions. This comparison is complicated by the experimental data being for only eight months of the year and the predictions being based on a full year.

#### COMPARISON OF EXPERIMENTAL AND PREDICTED DATA

##### Transmission Field Strengths

The experimental data were recorded at Choshi, Japan, which is on the coast, east of Tokyo, at 35° 42' N and 140° 51' E. The receiving points used for calculations by DECO were at every 10° latitude and longitude. The two points used by DECO that were closest to Choshi were at 30° N, 140° E, and 40° N, 140° E. Therefore, the predicted data for Choshi have been taken to be the average in voltage of that predicted for these two points. The predicted yearly field strengths of NPO, 24.0 kc/s transmissions with a radiated power of 250 kw taken from DECO'S Table VII for the receiving points of interest, are given in Table 1 of the present report. Also included

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are the averages for the two points which are taken to be the predictions for Choshi.

Table 1

Predicted Yearly Field Strengths  
of NPG at 24.0 kc/s  
with a Radiated Power of 250 kw

Receiver Location		Field Strength in db Above 1 $\mu$ V/m		
Latitude	Longitude	Daytime	Transition	Nighttime
40°N	140°E	39.6	40.7	43.0
30°N	140°E	39.0	39.9	41.9
35°N*	140°E*	39.3	40.3	42.6

\*Choshi values were taken as average in voltage of the values given for the other two locations.

It has been well established experimentally that the distribution of field strength with time is log-normal. The standard deviation,  $\sigma_e$ , of the field strength is dependent upon the solar condition of the propagation path. Since there were practically no experimental data available for aiding in the DECO calculations, DECO increased the estimated values of  $\sigma_e$  by one decibel to account for the uncertainties. According to Croghan\*\*, the values of  $\sigma_e$  used by DECO for calculations in the vicinity of Choshi were 3.6, 4.3, and 3.7 db for day, transition, and night, respectively. DECO also states that there is an additional uncertainty factor which is log-normally distributed with a standard deviation,  $\sigma_r$ , and which is also dependent upon the solar condition of the path. The values of  $\sigma_r$  used were 4 db for day, 5 db for transition, and 6 db for night. The functions yielding  $\sigma_e$  and  $\sigma_r$  are assumed to be independent, and therefore, the net standard deviation for field strength during the day is

$$\sigma_d = (\sigma_e^2 + \sigma_r^2)^{1/2} \quad (1)$$

where  $\sigma_e$  and  $\sigma_r$  are the daytime values. The standard deviations for the transitional and nighttime conditions,

\*\*Private communication with Mr. Roland Croghan of DECO Electronics, Inc.

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$\sigma_t$  and  $\sigma_n$ , respectively, can be similarly determined. Using Eq. (1) and the values given above, the predicted standard deviations for the NPG, 24.0 kc/s field strengths at Choshi were calculated to be 5.4 db for day, 6.6 db for transition, and 7.1 db for night.

The yearly field strengths predicted for Choshi from Table 1 were combined with the above standard deviations for day, transition, and night to give the field-strength distributions based on the DECO predictions, and are presented in Fig. 49. Also given in Fig. 49 are the Choshi experimental data from Fig. 44 increased by 24 db to account for the difference in radiated power. The average power radiated by NPG at 24.0 kc/s from October 1963 through May 1964 was 23.5 db above 1 kw or 224 kw. The measured and predicted data for the daytime and transitional propagation paths agree very well. The general level and shape of the observed nighttime data curves, in comparison with those for daytime and transition (Figs. 44 and 49) are not as expected. The data have been reverified, and there is no basis for considering the data to be erroneous. The differences between the day and night measured data could be the result of modal interference, or some equipment-produced diurnal problem resulting possibly from a diurnal ambient temperature cycle. Modal interference at such a distance (7.68 megameters) is not considered very likely, however. The predicted and measured NPG 24.0 kc/s field strengths at Choshi are compared in Table 2 for the three solar conditions of the propagation path and also for all hours combined, as will be discussed later. Since there were no seasonal effects considered in the predicted median field strengths for each path condition, the lack of a complete year of measured data does not alter this comparison.

Figure 49 shows the predicted probability distribution of the NPG field strengths during the periods when the propagation path to Choshi was in daylight, transition or darkness.

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Table 2

Comparison of Predicted and Measured Field Strengths  
of NPG (24.0 kc/s) at Choshi, Japan,  
for October 1963 through May 1964

Path Solar Condition	Median Field Strength (db Above 1 $\mu$ V/m)			Standard Deviation (db)		
	Predicted	Measured	Pred.- Meas.	Predicted	Measured	Pred.- Meas.
Day	39.3	41.7	-2.4	5.4	6.5	-1.1
Transition	40.3	43.3	-3.0	6.6	7.4	-0.8
Night	42.5	52.5	-10.0	7.1	3.5	3.6
All Hours	40.3	45.4	-5.1	6.4	8.0	-1.6

The probability that any field strength is exceeded during any period of time can be determined from

$$P_i = \Delta t_{d,i} p_d + \Delta t_{t,i} p_t + \Delta t_{n,i} p_n \quad (2)$$

where,  $P_i$

$\Delta t_{d,i}$ ,  $\Delta t_{t,i}$ , and  $\Delta t_{n,i}$

$p_d$ ,  $p_t$ , and  $p_n$

is the probability that the particular field strength will be exceeded during the period considered;

are the proportional parts of the period considered during which daytime, transition, and nighttime occurs over the entire propagation path, respectively; and

are the probabilities that the particular field strength will be exceeded during daytime, transition, or nighttime all along the path.

The experimental data presented in Fig. 49 were combined to give the cumulative probability distribution for all hours over the period of observation, October 1963 through May 1964, and this is shown in Fig. 50. Also included in Fig. 50 is the probability distribution of the signal field strength

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as would be predicted by DECO for the period October through May and obtained by using Eq. (2). The experimental data in Fig. 50 have a median value of 45.4 db above one microvolt per meter, with a standard deviation of 8 db. The predicted curve shows a median of 40.3 db above one microvolt per meter and a standard deviation of 6.4 db. These results are compared in Table 2. Comparing the predicted field-strength probability distribution with that observed for each season (Fig. 41) shows the greatest error to exist during spring. The errors for the fall and winter season are about equal but are less than those for the spring. Figure 5 of the DECO report has been reproduced and is presented as Fig. 52. This figure shows a prediction that, when considering all hours of the year, a field strength of 20 microvolts per meter (26 db above one microvolt per meter) would be exceeded about 99 percent of the time at Choshi (east of Tokyo). The observed data presented in Fig. 50 show that this field strength was exceeded by 98.5 percent of the data samples recorded from October through May.

Atmospheric Noise

Certain assumptions had to be made concerning the atmospheric-noise data recorded at Choshi. Based on these assumptions, which were discussed in more detail previously, the observed atmospheric-noise data as reported for Choshi are average values in a 100-cps bandwidth. The atmospheric-noise values used by DECO are the rms values in a 1-kc/s bandwidth and are the values predicted by C.C.I.R. (3). The precise conversion of average atmospheric noise levels to rms requires that the instantaneous amplitude probability distribution of the noise be known. This value is not known. However, the C.C.I.R. report (3) provides approximate values for the ratio of the rms to average voltage,  $V_d$ , based on many amplitude-probability distributions recorded at various locations throughout the world. This ratio,  $V_d$ , varies with location, season, and time of day. However, since there is not a great variation in  $V_d$  predicted for the Choshi area for the seasons of interest, an average value of  $V_d$  was used in converting the Choshi data to rms for comparison. The values of  $V_d$  for the Choshi area for all time periods from fall through spring were within 2 db of the average value used, 8.4 db. Since the bandwidth-conversion ratio from 100 cps to 1 kc/s is 10 db, the average noise values recorded at Choshi in a 100-cps bandwidth can be converted to rms in a 1-kc/s bandwidth by adding 18.4 to all observed data presented for the overall

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period of October through May. More precisely, the ratios are 18.7 db, 18.3 db, and 18.1 db for the periods September through November, December through February, and March through May, respectively.

The cumulative probability distribution for the Choshi data for each season are presented in Fig. 43, with the combined distribution for all data samples from October through May given in Fig. 48. The median values for the observed average noise data in a 100-cps bandwidth, as presented, in Figs. 43 and 48, were increased by the appropriate factors to convert them to rms noise in a 1-kc/s bandwidth, and are given in Table 3 along with the noise data given by DECO. Everything considered, the agreement of the two sets of data is very good.

Table 3  
Comparison of Predicted\* and Measured  
Atmospheric Noise Levels at Choshi, Japan,  
From October 1963 through May 1964

Season**	Median rms Atmospheric Noise in 1-kc/s Bandwidth (db Above 1 $\mu$ V/m)		
	Predicted	Measured	Predicted-Measured
Fall	42.2	38.7	3.5
Winter	37.3	36.8	0.5
Spring	39.8	44.0	-4.2
Fall-Spring	39.9	38.4	1.5

\*From C.C.I.R. Report 322 (3).

\*\*Season in northern hemisphere.

Signal-to-Noise Ratios

The reliability of a communication circuit is, of course, dependent upon the available signal-to-noise ratio. The previous comparisons of the measured and predicted NPG field strengths and atmospheric noise show rather good agreement, in general. However, because of the time correlation of the signal and noise levels, it does not necessarily follow that the predicted and measured signal-to-noise ratios will also

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show good agreement.

The cumulative probability distributions for the observed NPG (24.0 kc/s) signal to atmospheric noise ratios for all data samples are presented in Fig. 42 for each season and in Fig. 45 for each solar condition of the NPG propagation path. The same information for all data samples combined for the period of observation is presented in Fig. 47. It should be noted that the values given in Figs. 42 and 45 are the ratios of the signal field strength, normalized to a radiated power of one kilowatt, to the average atmospheric noise in a 100-cps bandwidth.

The data as presented in Fig. 47 were converted to the ratios of NPG field strength for a radiated power of 250 kilowatts to the rms atmospheric noise in a 1-kc/s bandwidth and are shown in Fig. 51. Also included in Fig. 51 is the predicted signal-to-noise probability distribution, as given for the Choshi, Japan, area by Fig. IV - 4 of the DECO report. The predicted median signal-to-noise ratio given by Fig. 51 is 0.4 db, while the measured value is 6.5 db. The predicted and measured standard deviations are 12.4 and 9.5 db, respectively. If the receiving-system required signal-to-noise ratio is known, the communication reliability can be determined from Fig. 51. DECO states that the required signal to rms atmospheric noise ratio in a 1-kc/s bandwidth is 0 db for manual cw and -3 db for automatic, 50-baud teletype when using the AN/BRR-3 receiver. Therefore, from Fig. 51 it can be seen that the observed communication reliability in the Choshi area is 76 percent for manual cw and 84 percent for the teletype. Figures 53 and 54, which are reproduced from Figs. 6 and 7 of the DECO report, show predicted reliabilities of about 52 and 62 percent for cw and teletype, respectively.

#### CONCLUSIONS

The predicted and measured values of NPG (24.0 kc/s) field strength, atmospheric noise, signal-to-noise ratios, and reliability all showed rather good agreement. The measured signal field strengths were, in general, higher than predicted. Comparison of the measured nighttime signal field strengths with those measured during daytime or transition indicated the possibility that the nighttime values were somewhat erroneously high. If this were the true situation, the overall agreement of the predicted and measured signal field strengths and communication reliability would be closer, since the predicted and measured atmospheric noise levels

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showed very good agreement. When it is realized that at the time the DECO predictions were made there were very little experimental data from which to determine the propagation parameters, the agreement is rather remarkable.

It has been demonstrated here that the DECO predictions for the general area around the southeastern part of Japan agree very well with experimental data. However, it is not intended to be inferred that there should necessarily be good agreement throughout the entire area covered by the DECO predictions. It is, nevertheless, quite probable that the predicted field strengths would have approximately the same accuracy throughout the prediction area as was shown at Choshi.

There were some experimental vlf propagation data recorded on the ground in Guam and Japan and aboard an aircraft in flight between California and that area during May, June, and July 1965. These data were primarily for transmissions from NPM and Haiku in Hawaii while operating on various frequencies between 16.6 and 26.1 kc/s. The airborne experiment was conducted and reported by NRL (2). The ground-based experiment was carried out by DECO Electronics, Inc., and will soon be reported by them. The results of these investigations will contribute greatly toward improving the accuracy of future vlf communication reliability predictions.

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2. Rhoads, F.J., and Garner, W.E., "An Investigation of the Modal Interference of Very Low Frequency Radio Waves," NRL Report 6359, Oct. 27, 1965
3. International Radio Consultative Committee (C.C.I.R.), "World Distribution and Characteristics of Atmospheric Radio Noise," Report 322, Geneva 1963

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LIST OF ILLUSTRATIONS

24.0 kc/s Data Recorded at Choshi, Japan

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- Fig. 2 Hourly mean and standard deviation of NPG signal to atmospheric noise ratios during October 1963
- Fig. 3 Hourly mean and standard deviation of atmospheric noise during October 1963
- Fig. 4 Probability distributions of NPG and atmospheric noise field strengths for all hours recorded during October 1963
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- Fig. 26 Hourly mean and standard deviation of NPG field strengths during March 1964
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- Fig. 47 Probability distribution of NPG signal to atmospheric noise ratios for all hours recorded from October 1963 through May 1964
- Fig. 48 Probability distribution of atmospheric noise for all hours recorded from October 1963 through May 1964

Comparison of Observed 24.0 kc/s Data From Choshi, Japan  
With DECO'S Predicted Data

- Fig. 49 Probability distributions of predicted and observed (from Fig. 44) NPG field strengths for all hours when propagation path was in daylight, transition, or darkness
- Fig. 50 Probability distributions of predicted and observed (from Fig. 46) NPG field strengths for all hours from October through May
- Fig. 51 Probability distribution of predicted and observed NPG signal to atmospheric noise ratios for all hours of the year for the predicted data, and for all hours recorded from October 1963 through May 1964 for the observed (from Fig. 47, modified for bandwidth and rms noise)

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DECO'S Predicted Reliability Contour Maps  
For MPG, 24.0 kc/s

- Fig. 52 Percent of time that the field strength exceeds 20 microvolts per meter for all hours of the year
- Fig. 53 Percent of all hours of the year that cw communication will be reliable
- Fig. 54 Percent of all hours of the year that 50-baud teletype communication will be reliable

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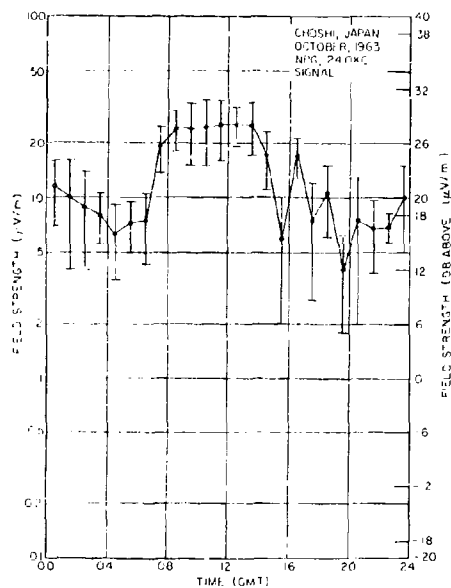


Fig. 1

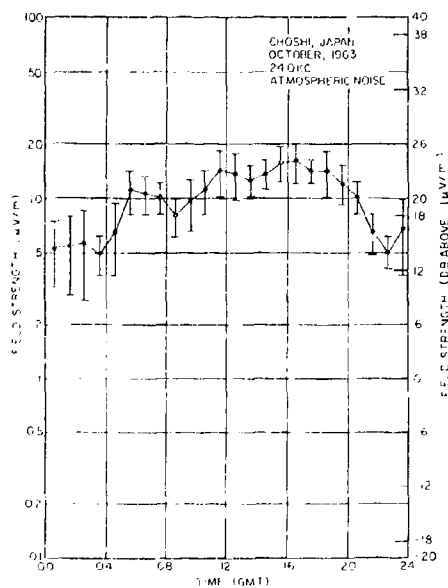


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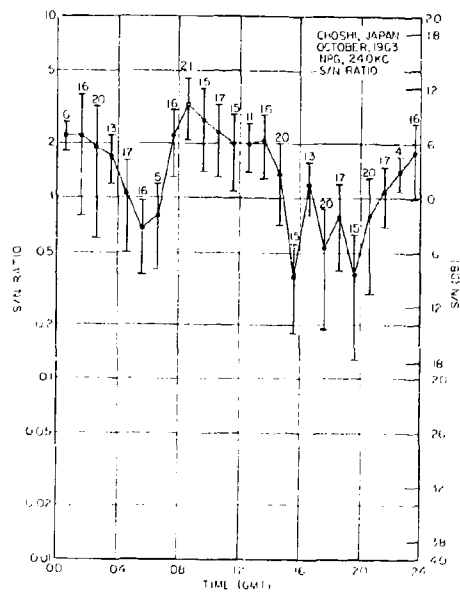


Fig. 2

Note: NPG radiated power normalized to 1 kw. Atmospheric noise is average value in a 100-cps bandwidth.



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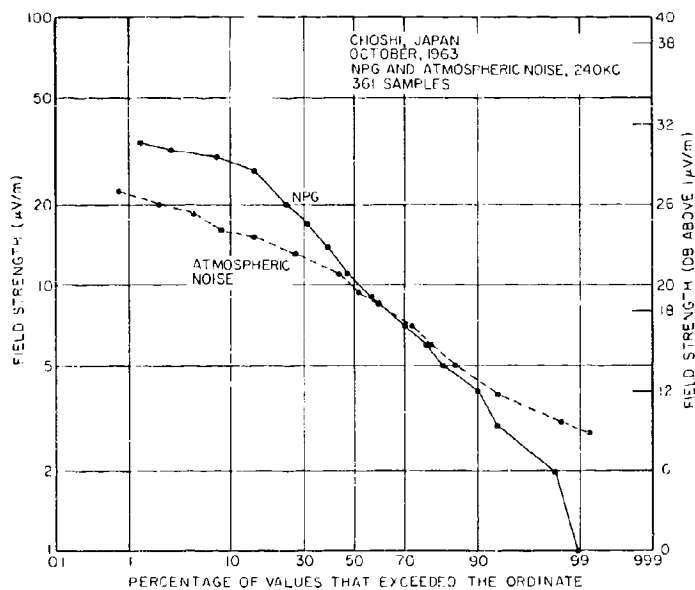


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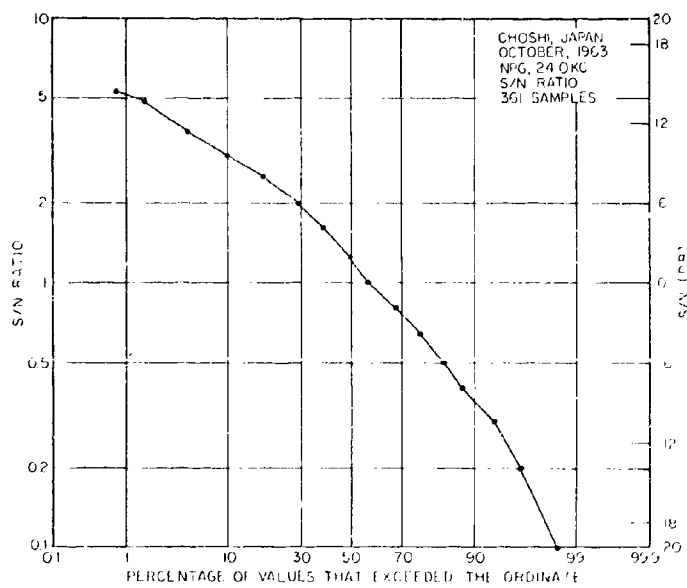


Fig. 5

Note: NPG radiated power normalized to 1 kw.  
Atmospheric noise is average value in a  
100-cps bandwidth.

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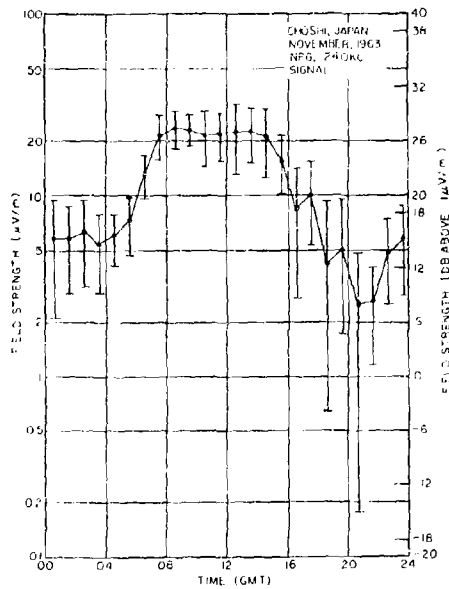


Fig. 6

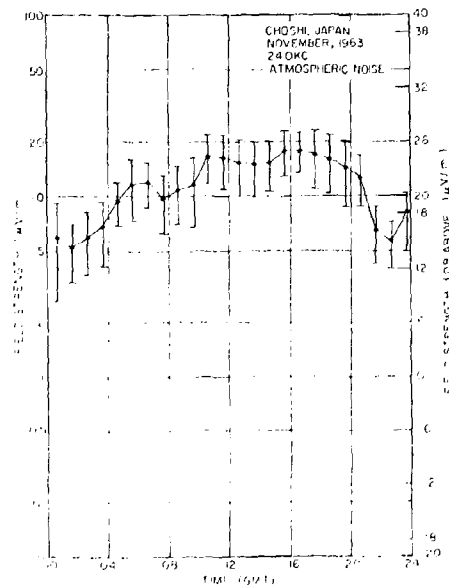


Fig. 8

Note: NPG radiated power normalized to 1 kw. Atmospheric noise is average value in a 100-cps bandwidth.

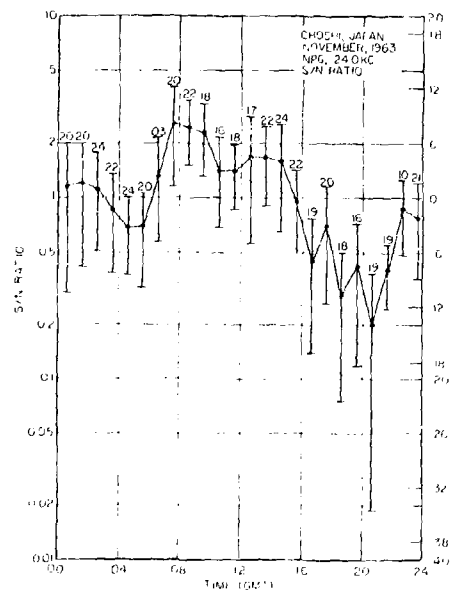


Fig. 7

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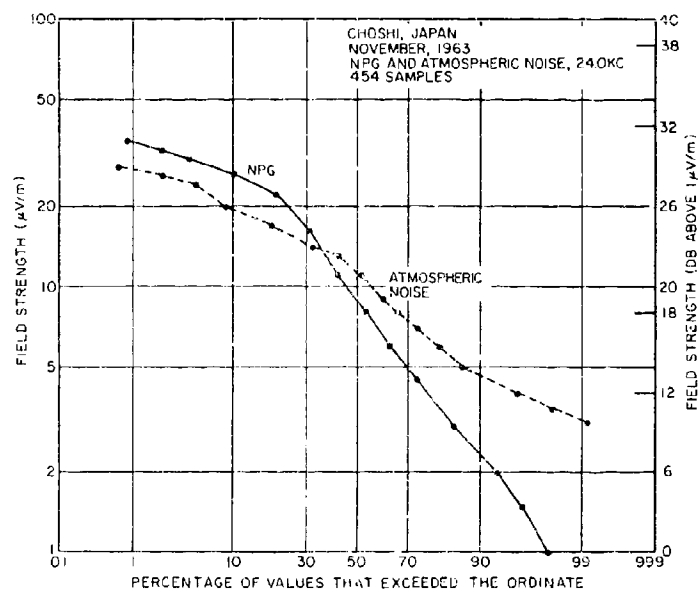


Fig. 9

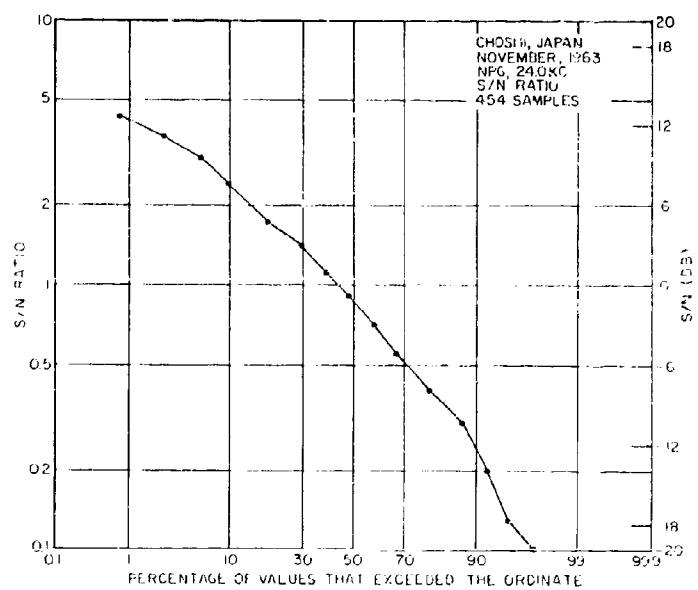


Fig. 10

Note: NPG radiated power normalized to 1 kw.  
Atmospheric noise is average value in a  
100-cps bandwidth.

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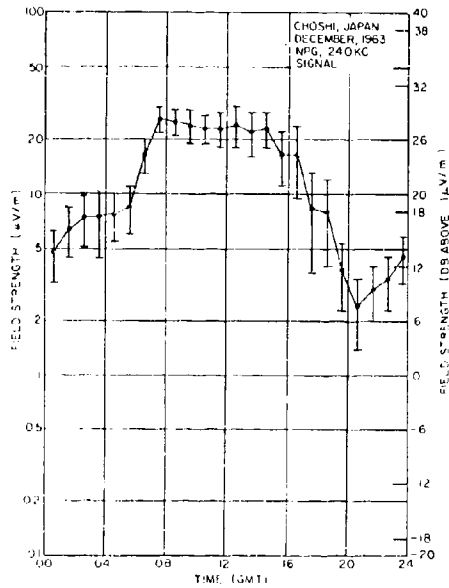


Fig. 11

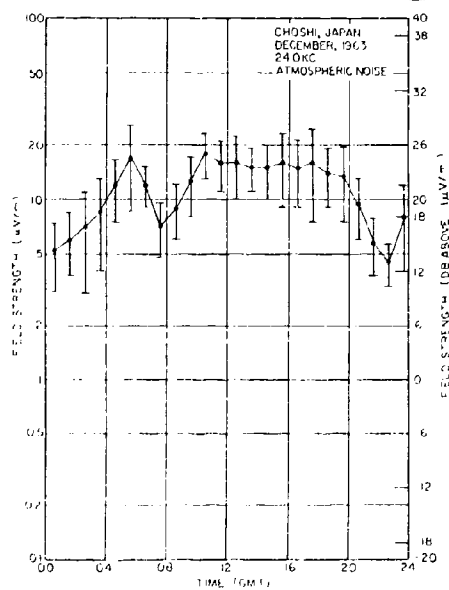


Fig. 13

Note: NPG radiated power normalized to 1 kw. Atmospheric noise is average value in a 100-cps bandwidth.

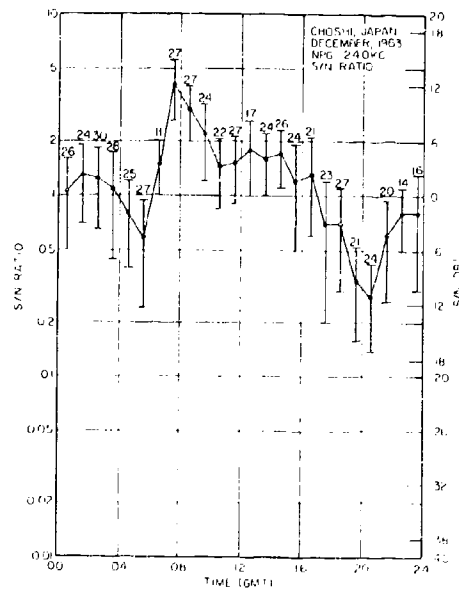


Fig. 12

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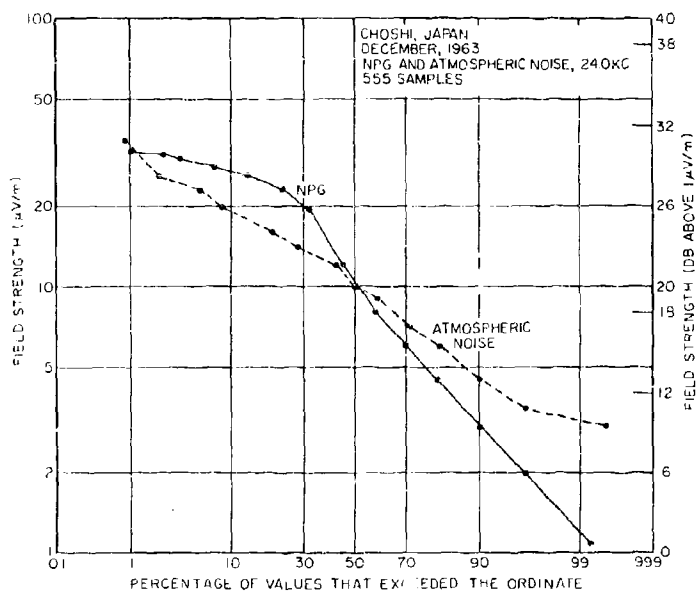


Fig. 14

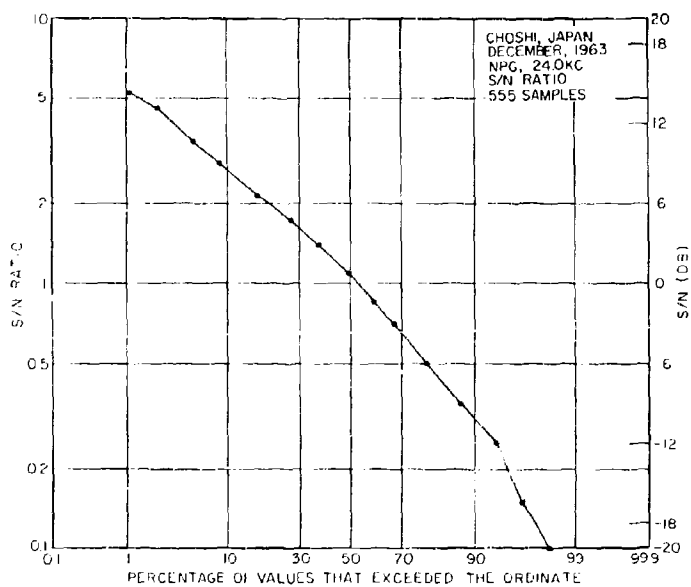


Fig. 15

Note: NPG radiated power normalized to 1 kw.  
Atmospheric noise is average value in a  
100-cps bandwidth.

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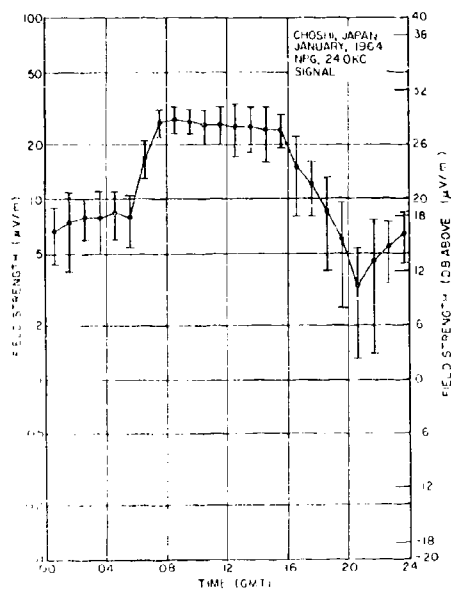


Fig. 16

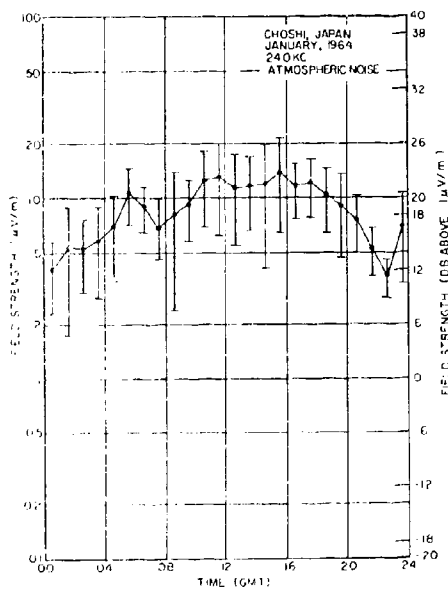


Fig. 18

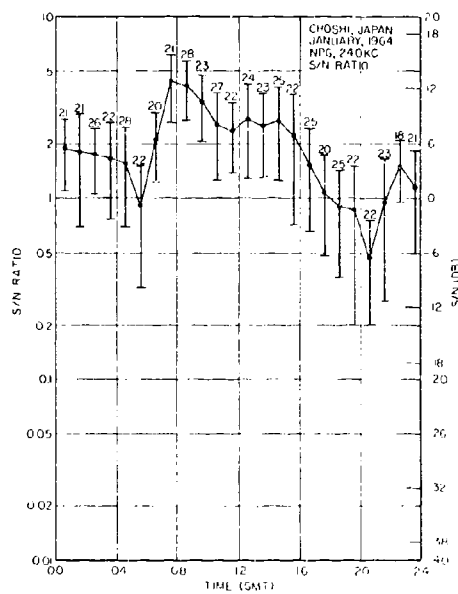


Fig. 17

Note: NPG radiated power normalized to 1 kw. Atmospheric noise is average value in a 100-cps bandwidth.

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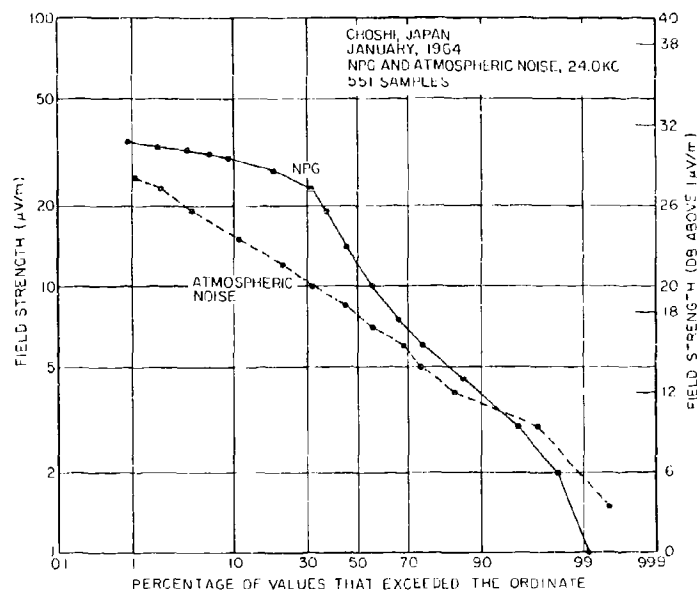


Fig. 19

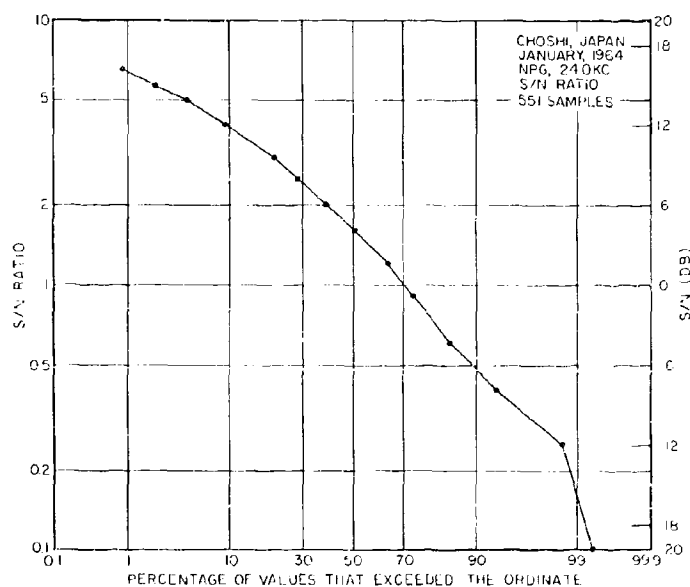


Fig. 20

Note: NPG radiated power normalized to 1 kw.  
Atmospheric noise is average value in a  
100-cps bandwidth.

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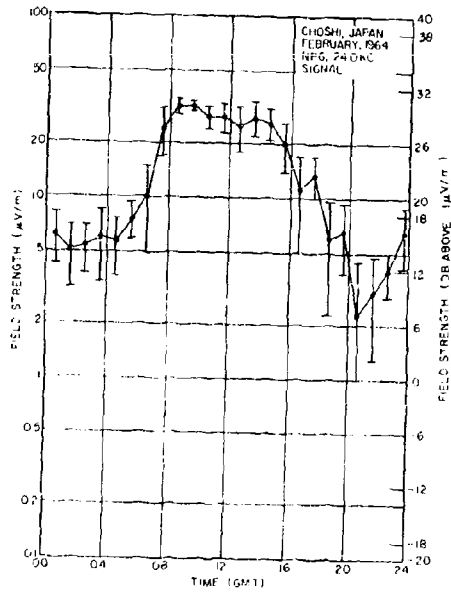


Fig. 21

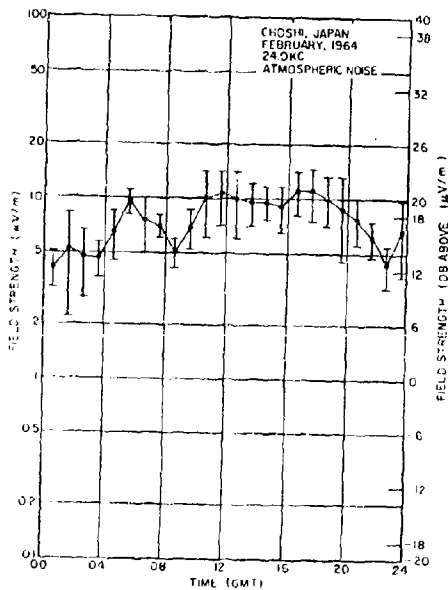


Fig. 23

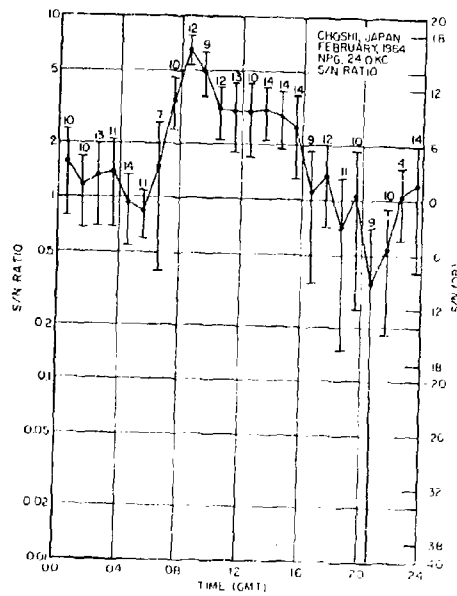


Fig. 22

Note: NPG radiated power normalized to 1 kw. Atmospheric noise is average value in a 100-cps bandwidth.



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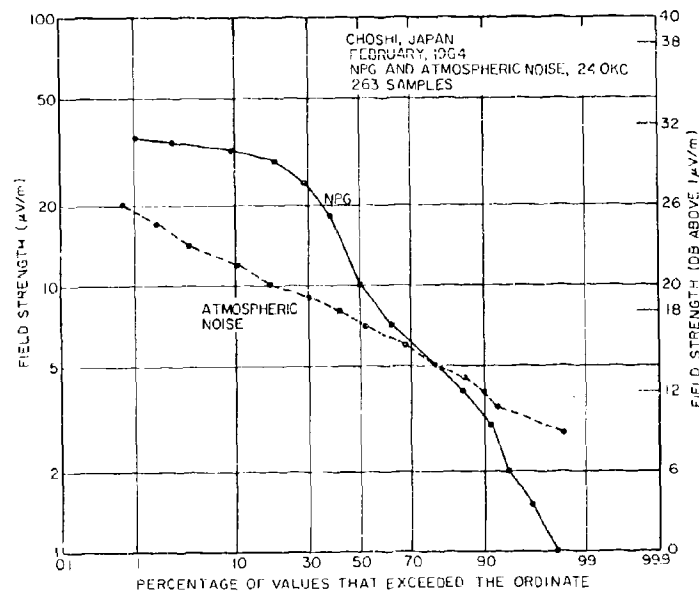


Fig. 24

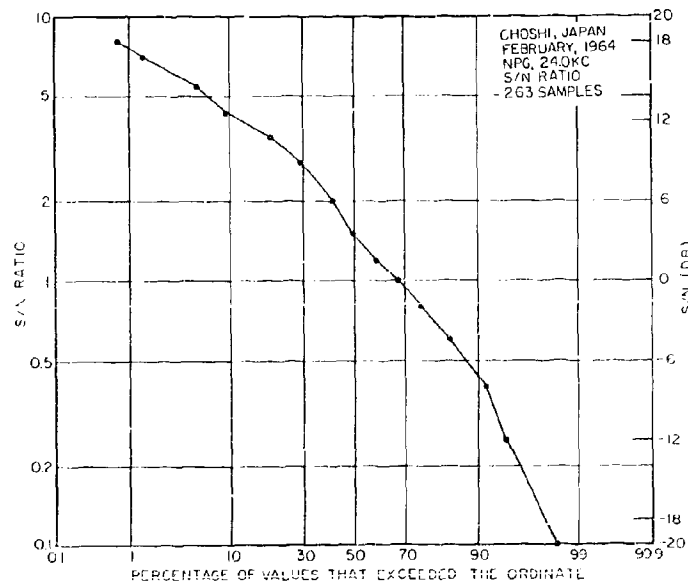


Fig. 25

Note: NPG radiated power normalized to 1 kw.  
Atmospheric noise is average value in a  
100-cps bandwidth.

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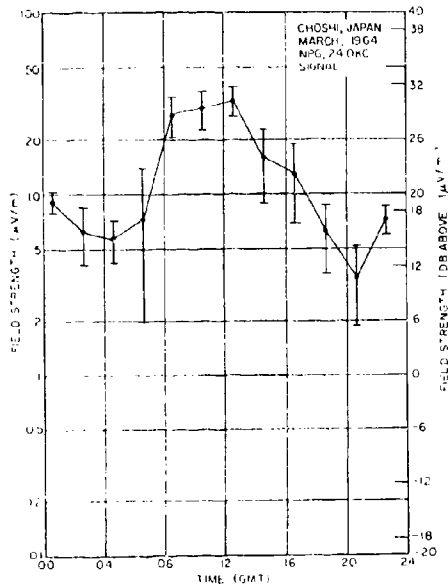


Fig. 26

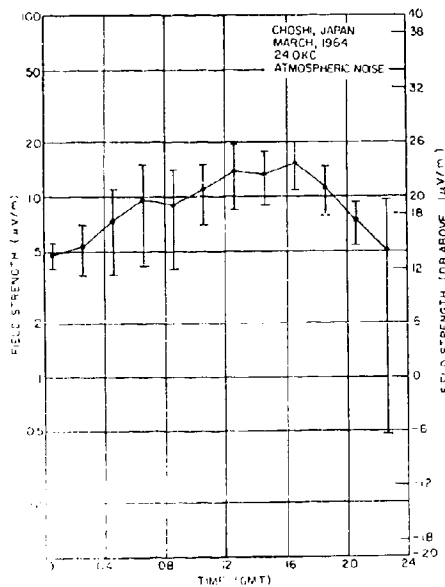


Fig. 28

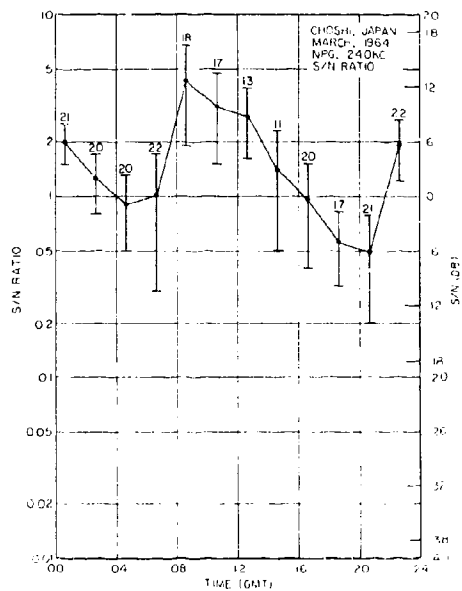


Fig. 27

Note: NPG radiated power normalized to 1 kw. Atmospheric noise is average value in a 100-cps bandwidth.

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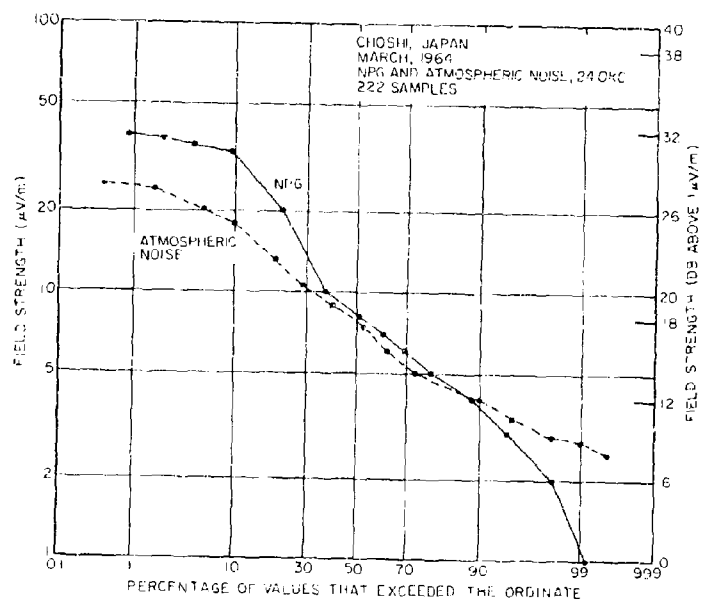


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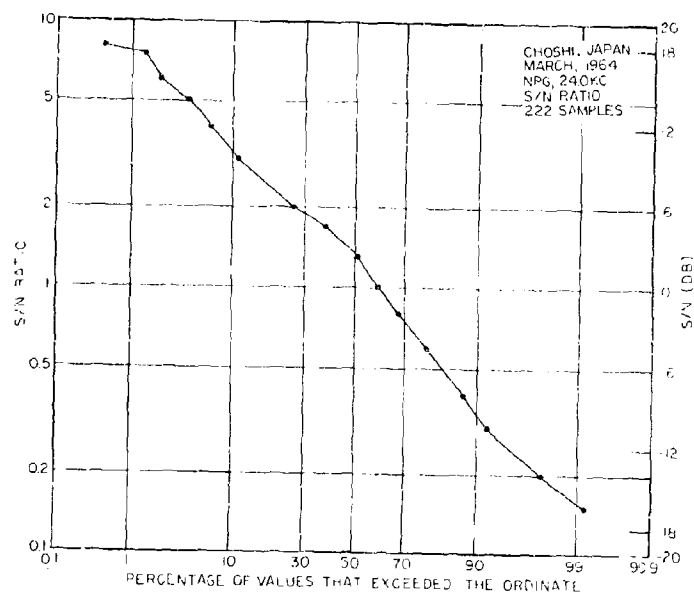


Fig. 30

Note: NPG radiated power normalized to 1 kw.  
Atmospheric noise is average value in a  
100-cps bandwidth.

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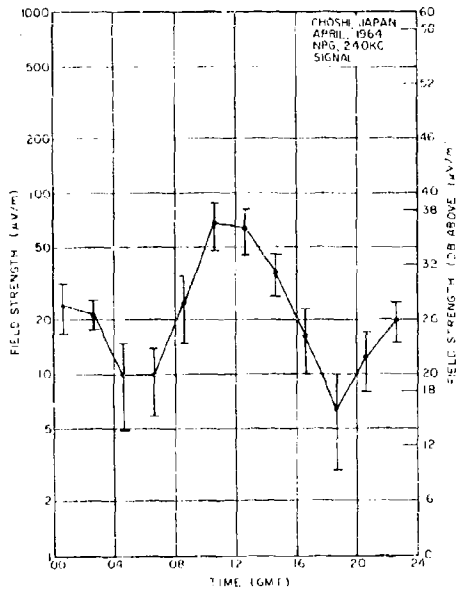


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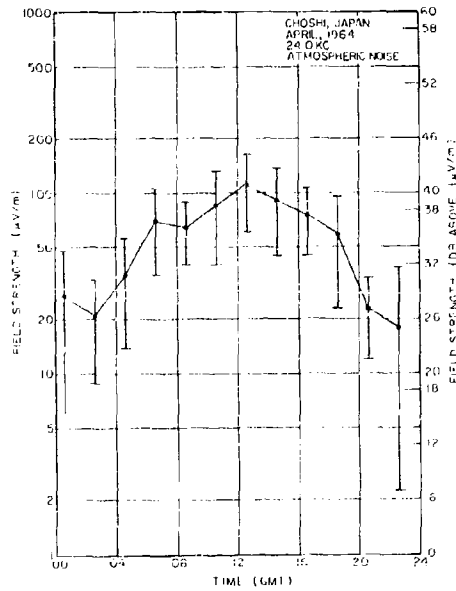


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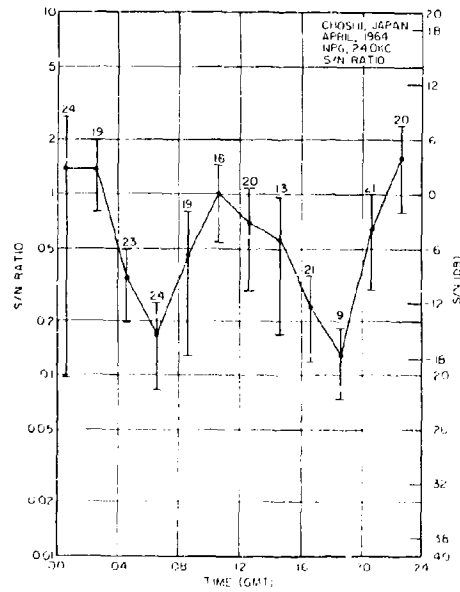


Fig. 32

Note: NFG radiated power normalized to 1 kw. Atmospheric noise is average value in a 100-cps bandwidth.

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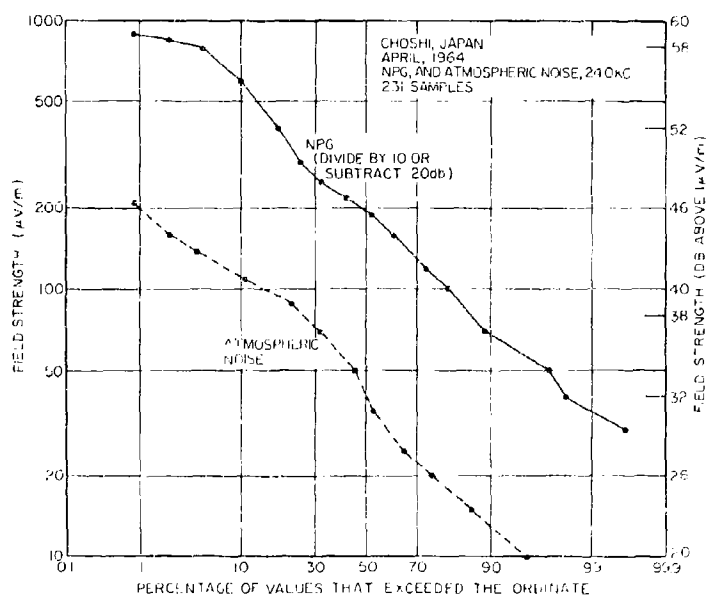


Fig. 34

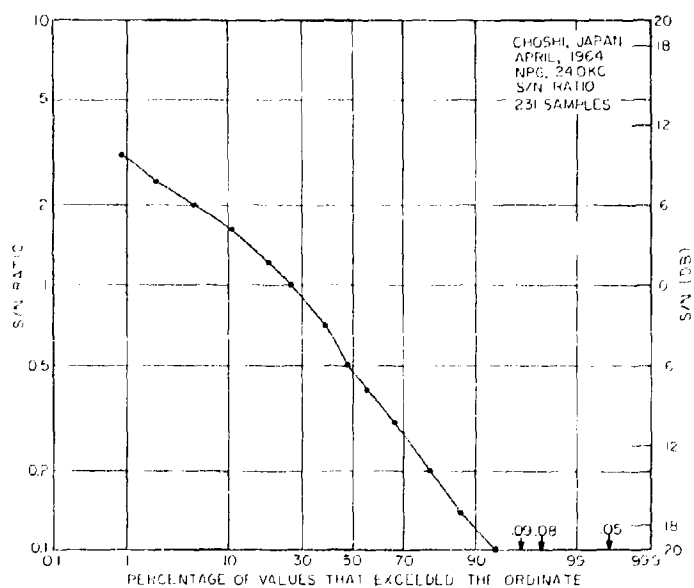


Fig. 35

Note: NPG radiated power normalized to 1 kw.  
Atmospheric noise is average value in a  
100-cps bandwidth.

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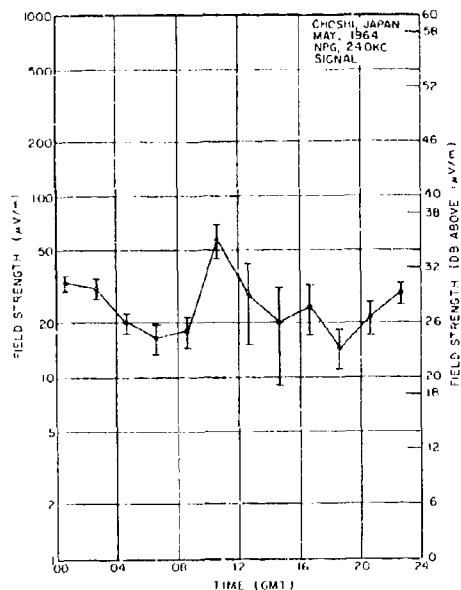


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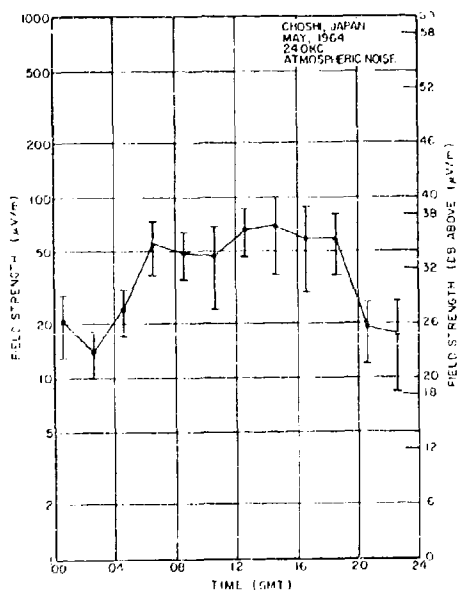


Fig. 38

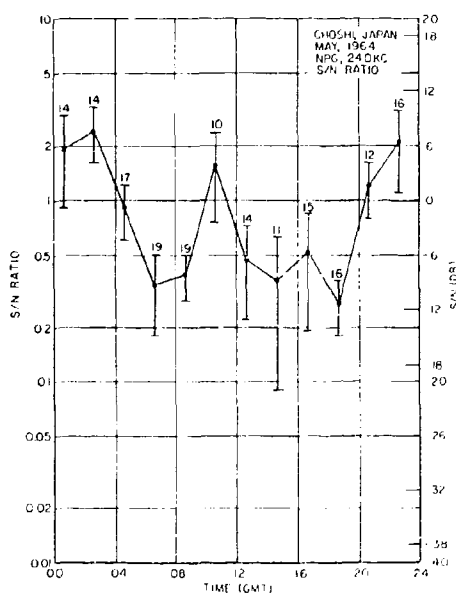


Fig. 37

Note: NPG radiated power normalized to 1 kw. Atmospheric noise is average value in a 100-cps bandwidth.

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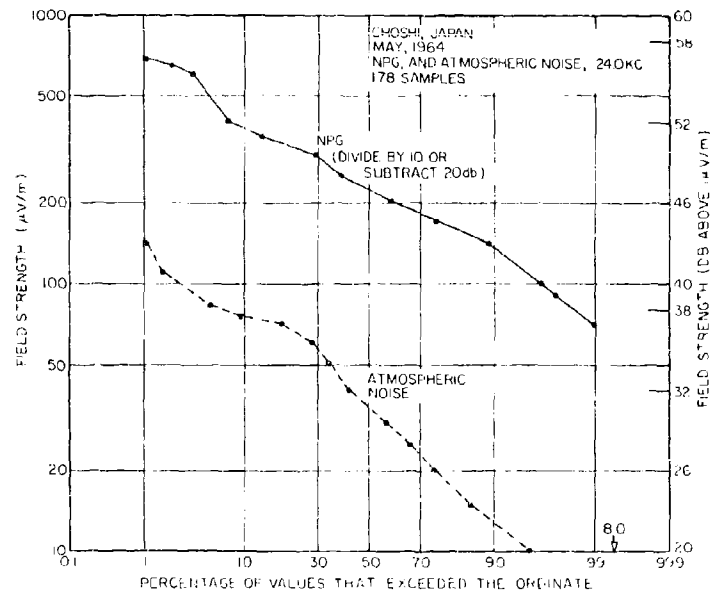


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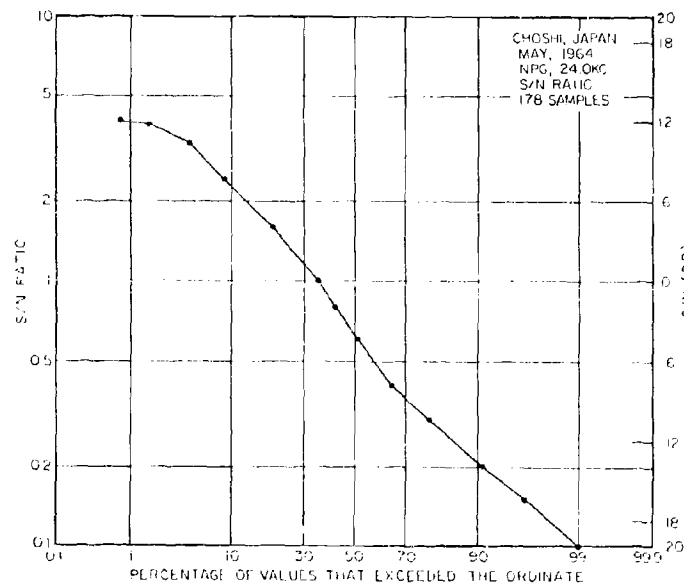


Fig. 40

Note: NPG radiated power normalized to 1 kw.  
Atmospheric noise is average value in a  
100-cps bandwidth.

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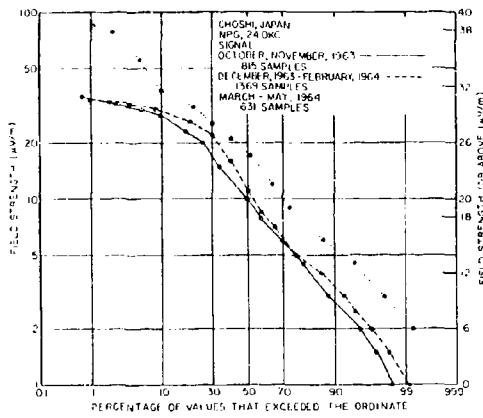


Fig. 41

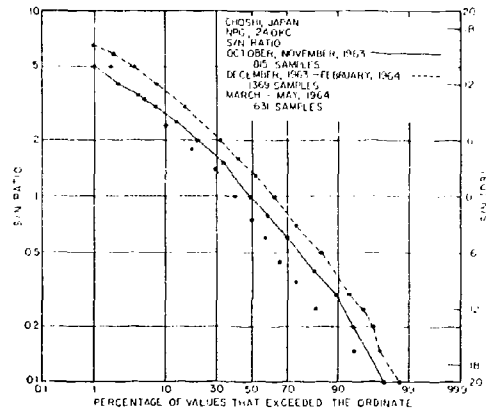


Fig. 42

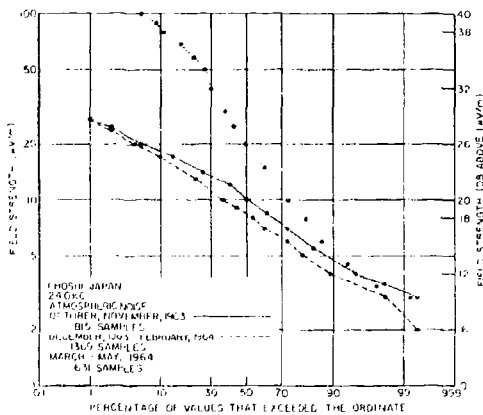


Fig. 43

Note: NPG radiated power normalized to 1 kw. Atmospheric noise is average value in a 100-cps bandwidth.



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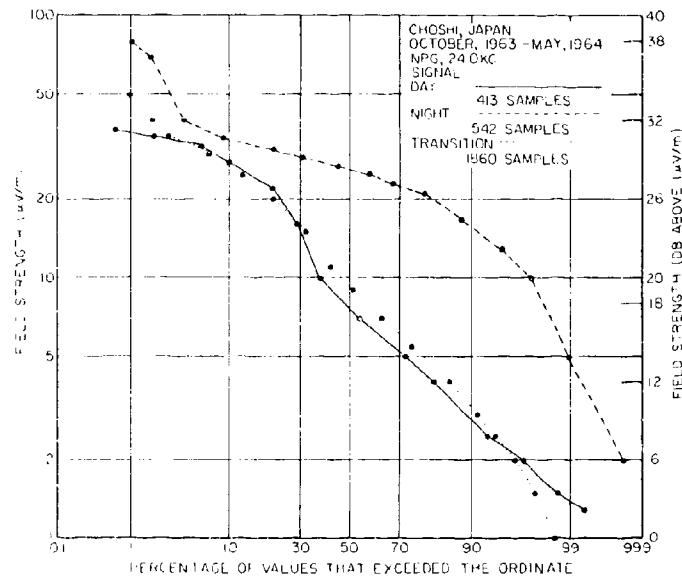


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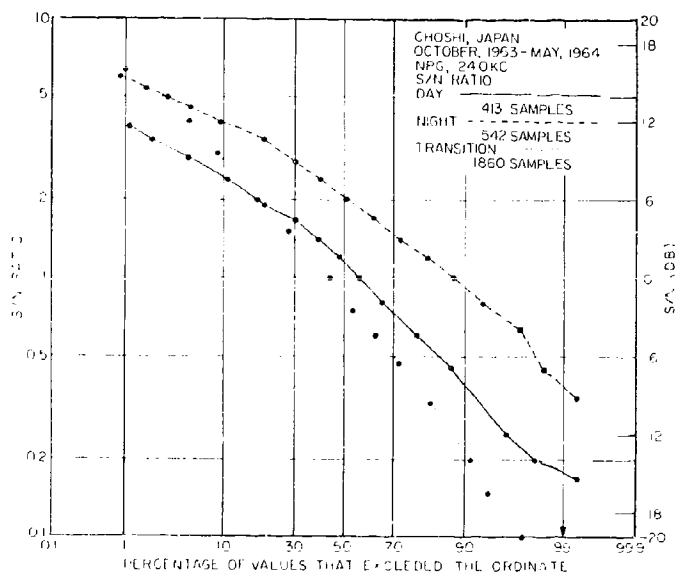


Fig. 45

Note: NPG radiated power normalized to 1 kw.  
Atmospheric noise is average value in a  
100-cps bandwidth.

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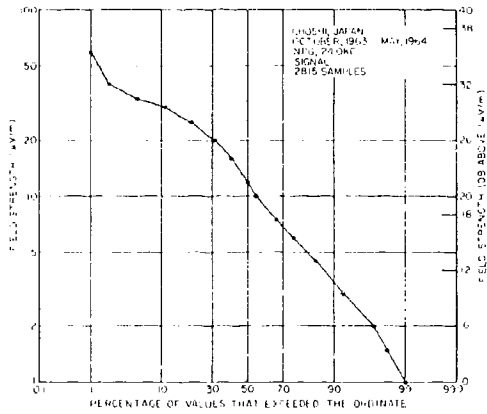


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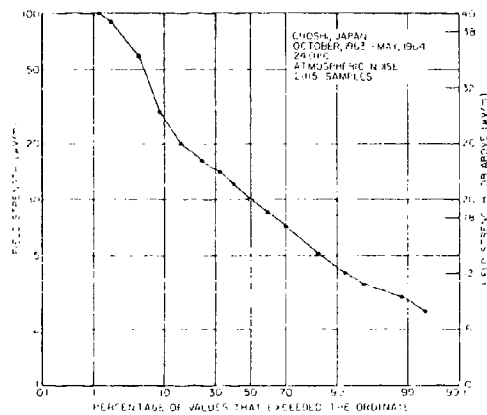


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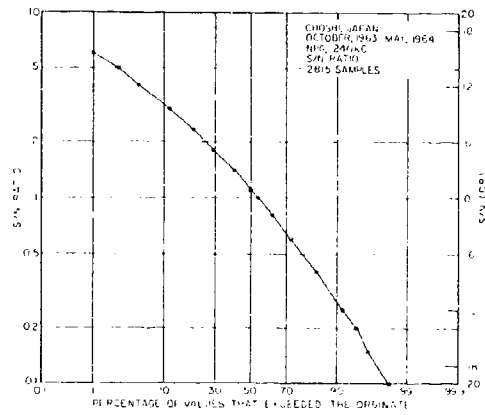


Fig. 47

Note: NPC radiated power normalized to 1 kw. Atmospheric noise is average value in a 100-cps bandwidth.

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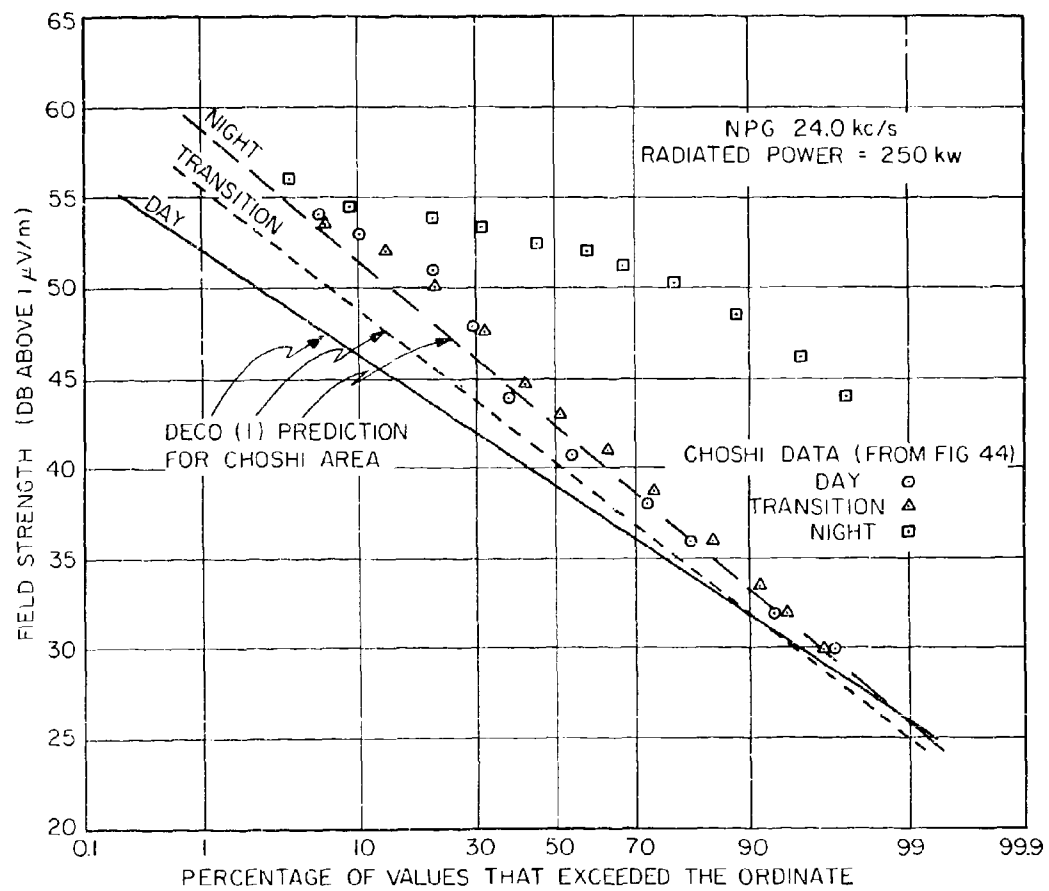


Fig. 49

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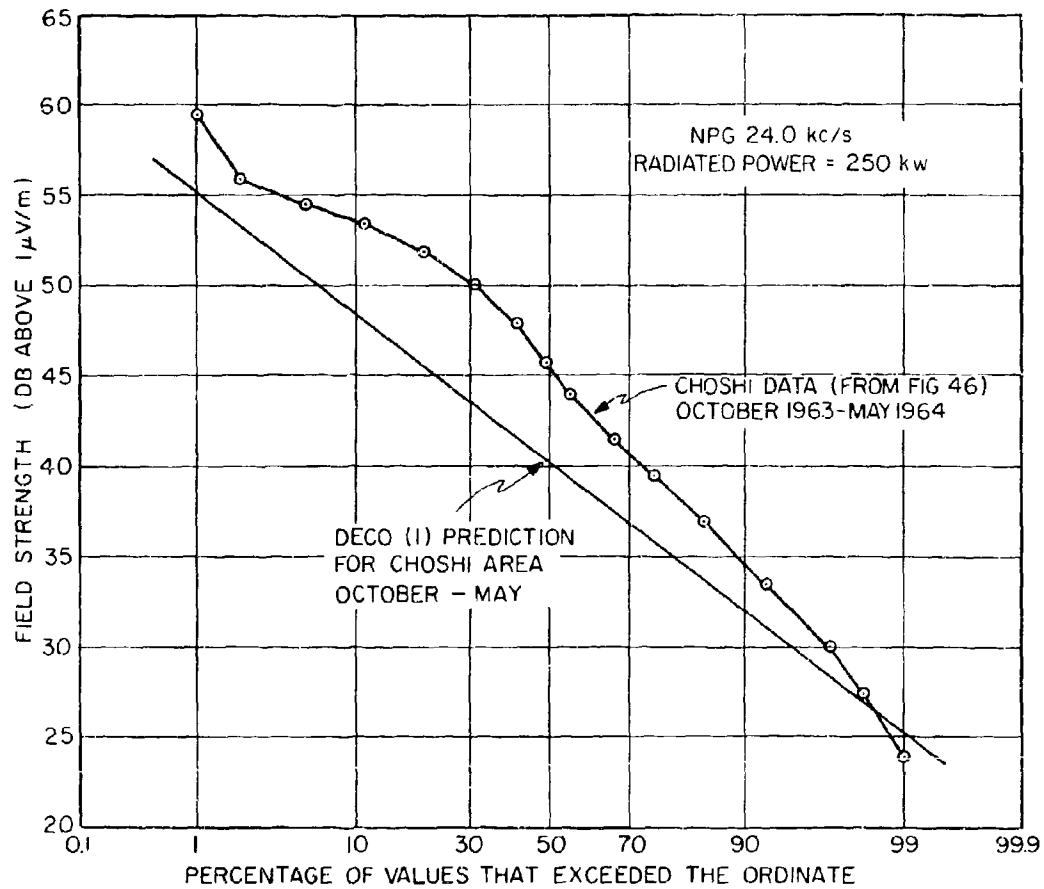


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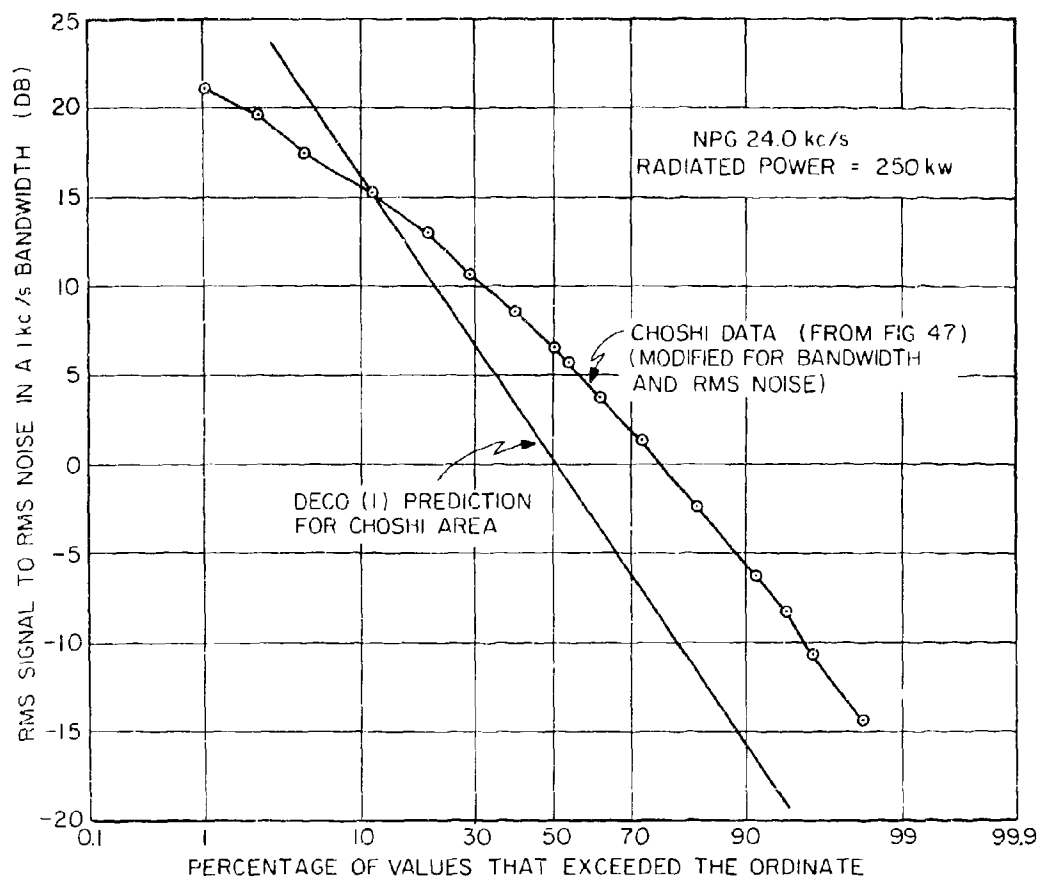


Fig. 51

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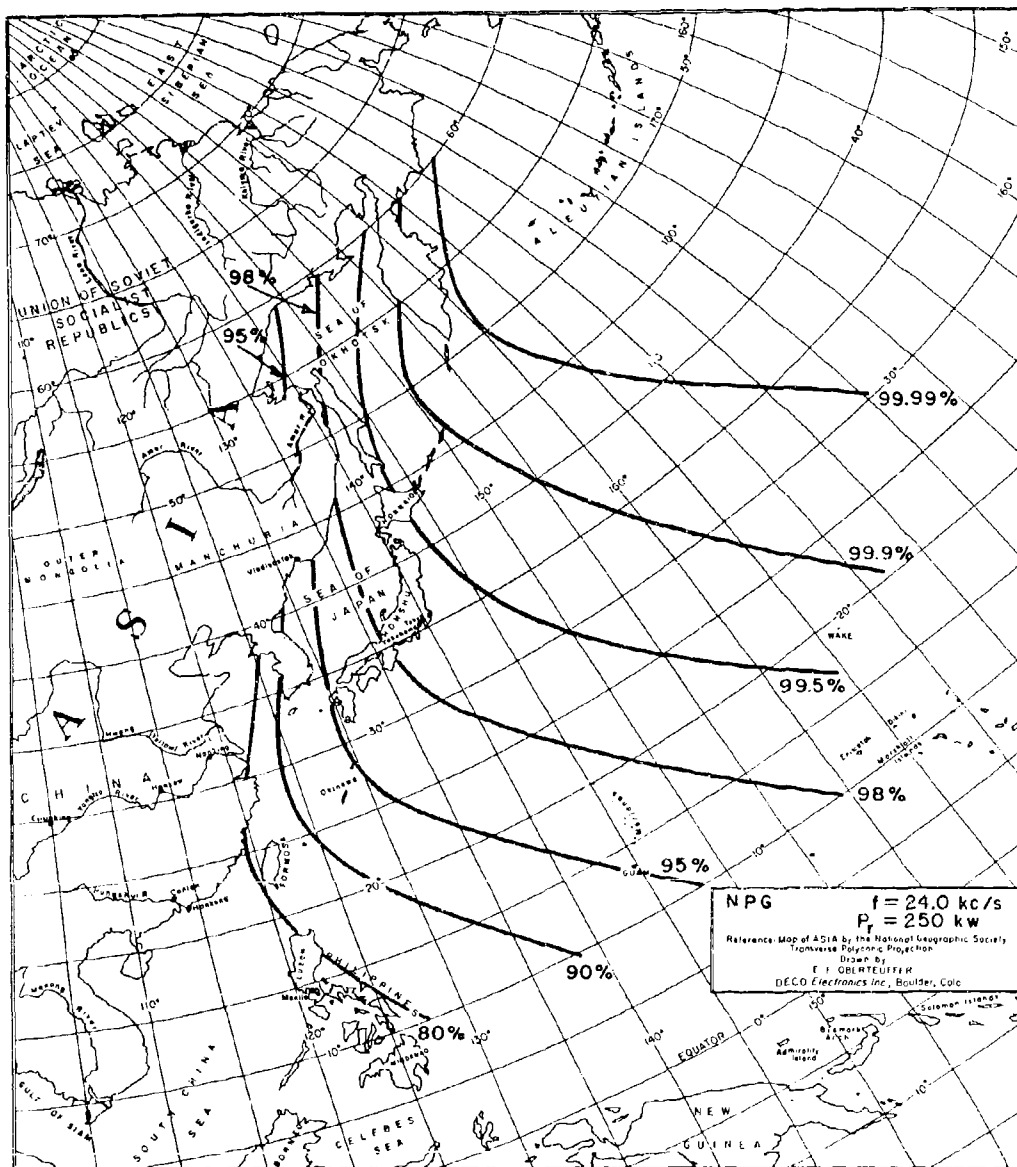


Fig. 52

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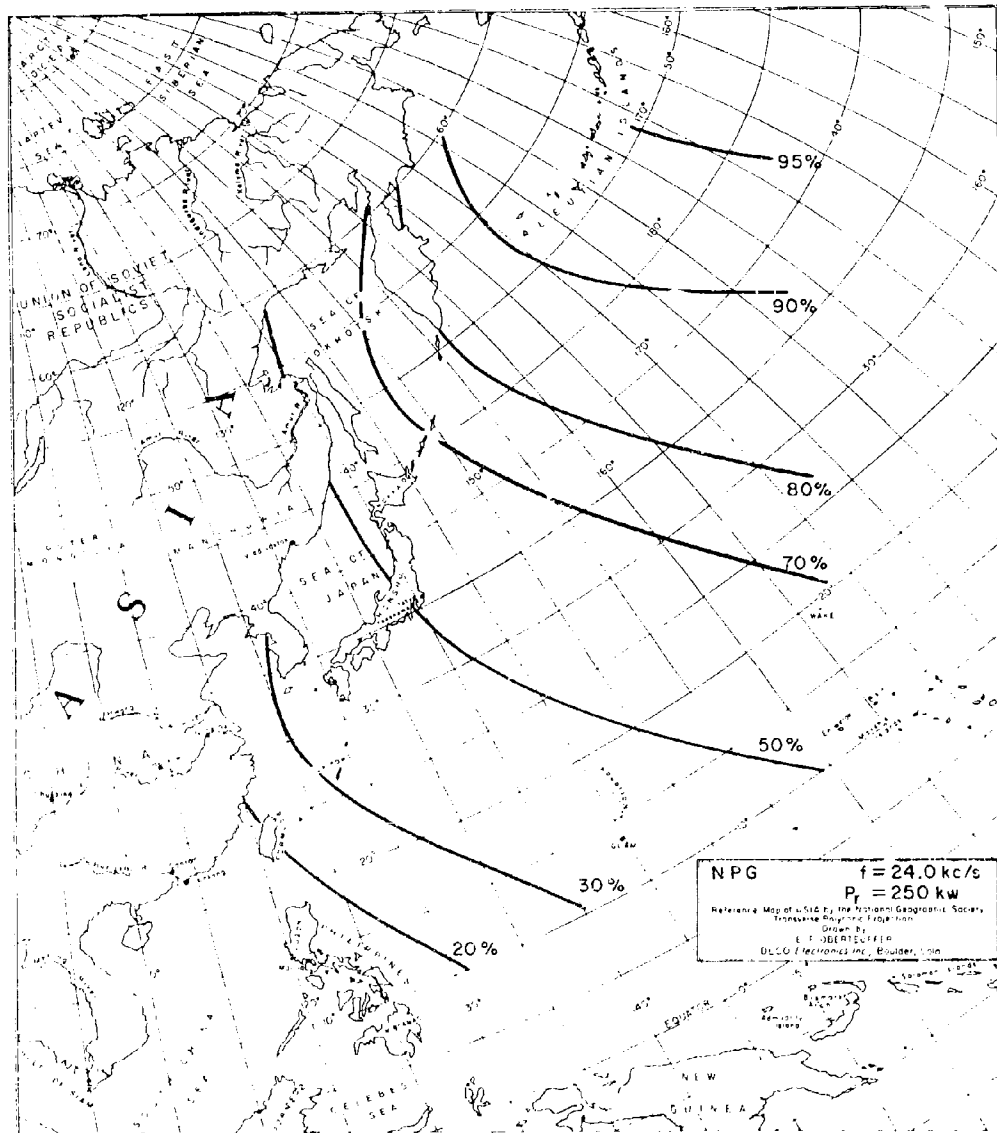


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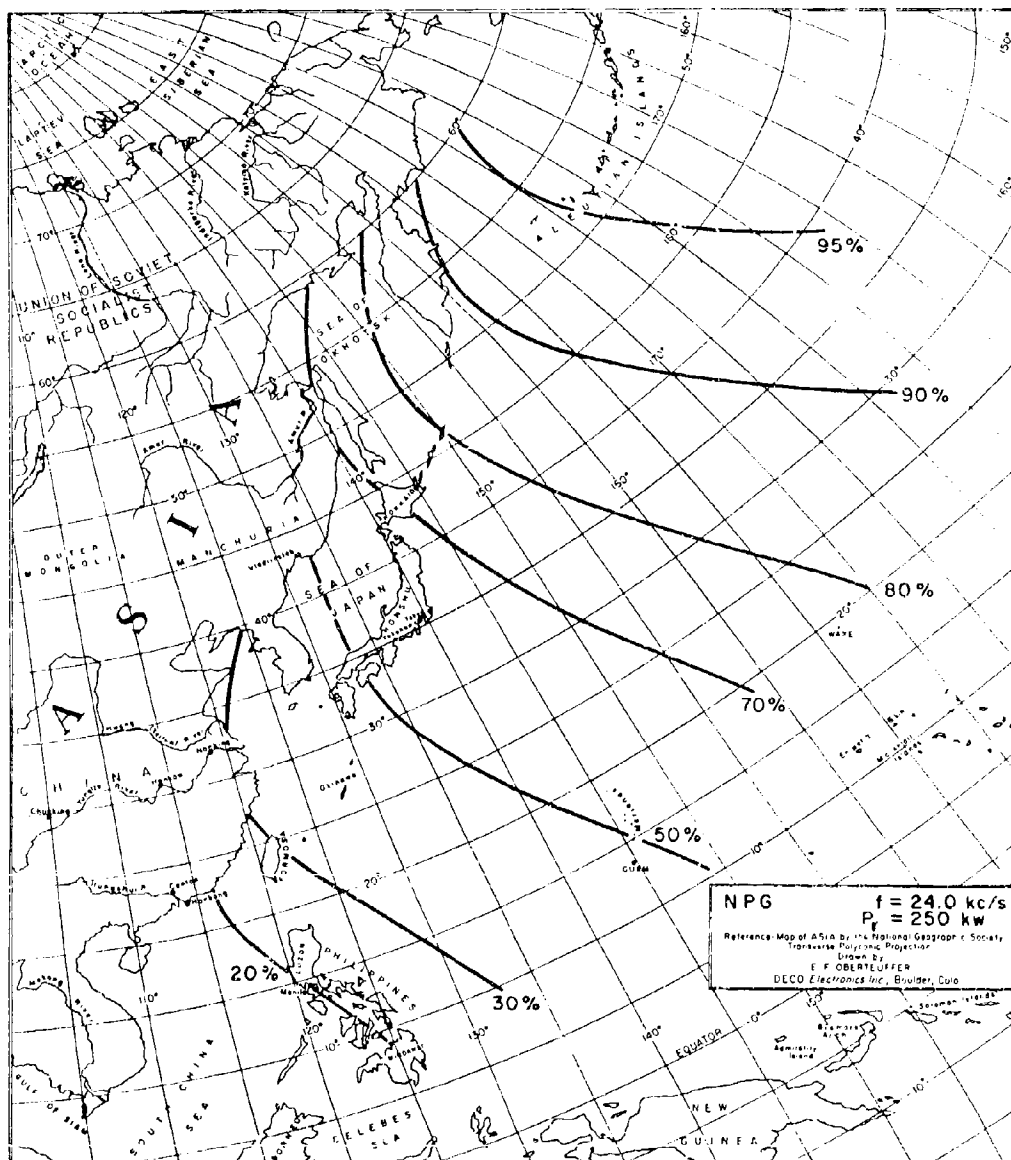


Fig. 54



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4 DESCRIPTIVE NOTES (Type of report and inclusive dates)		
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13 ABSTRACT		
<p>In 1963, the operating frequency of the very-low-frequency vlf transmitting station NPG, located near Seattle, Washington, was changed from 18.6 kc/s to 24.0 kc/s. DECO Electronics, Inc., was contracted to predict the communication reliability of the NPG 24.0 kc/s transmissions in the western Pacific Ocean area. Through the generosity of a Japanese research group at the Inubo Radio Wave Observatory in Choshi, Japan, some experimental data were obtained and have been used to evaluate the DECO predictions in a portion of the area covered, the southeast coast of Japan.</p> <p>Comparison of the experimental and predicted data show very good agreement. The received field strengths, as observed, were slightly higher than predicted. The predicted atmospheric noise levels showed very close agreement with the measured data. The observed communication reliability was about 76 percent for manual cw, and was predicted to be about 52 percent. For automatic teletype, the observed and predicted reliabilities were 84 and 62 percent, respectively. Therefore, for the ocean area in the vicinity of southeast Japan, the reliability of NPG 24.0 kc/s transmissions, assuming a radiated power of 250 kw, would be better than predicted.</p>		

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14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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